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EP 0470379 A1 EP 0231894 A1 US 4448865 A

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(54) Abstract Title

A method of depositing a carbon film on a membrane

(57) A carbon film is deposited on a membrane 2 (e.g. silicon) for use in X-ray or corpuscular projection lithography by off-axis sputtering from a target 5. A carbon film produced by off-axis sputtering has internal stresses that are approximately equal to those of a thin silicon membrane. For modifying the properties of the film after deposition, e.g. deactivation of chemically reactive sites or stress stabilisation, bombardment with helium ions can be employed.

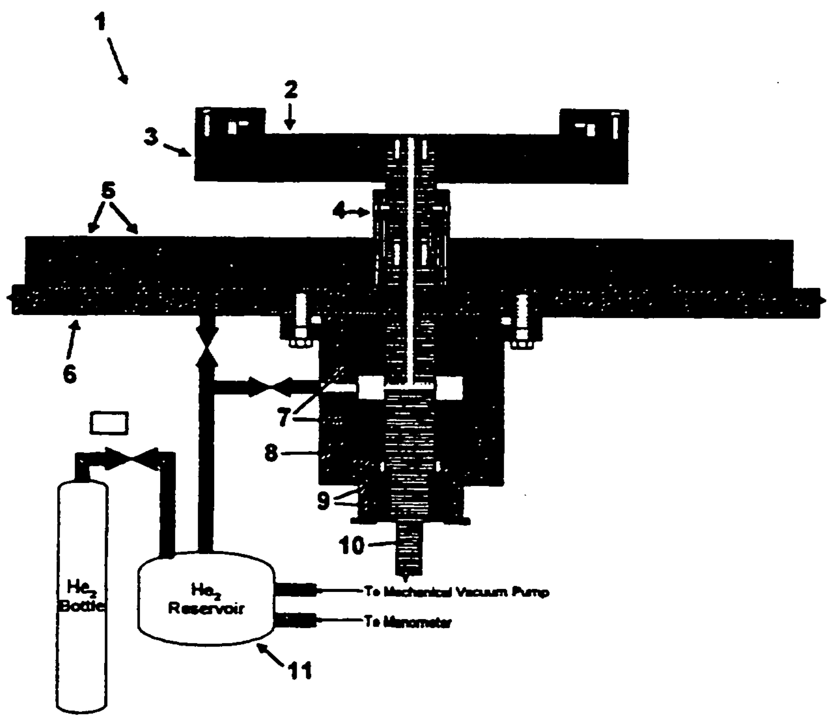

Fig. 1

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At least one drawing originally filed was informal and the print reproduced here is taken fr m a later filed f rmal c py.

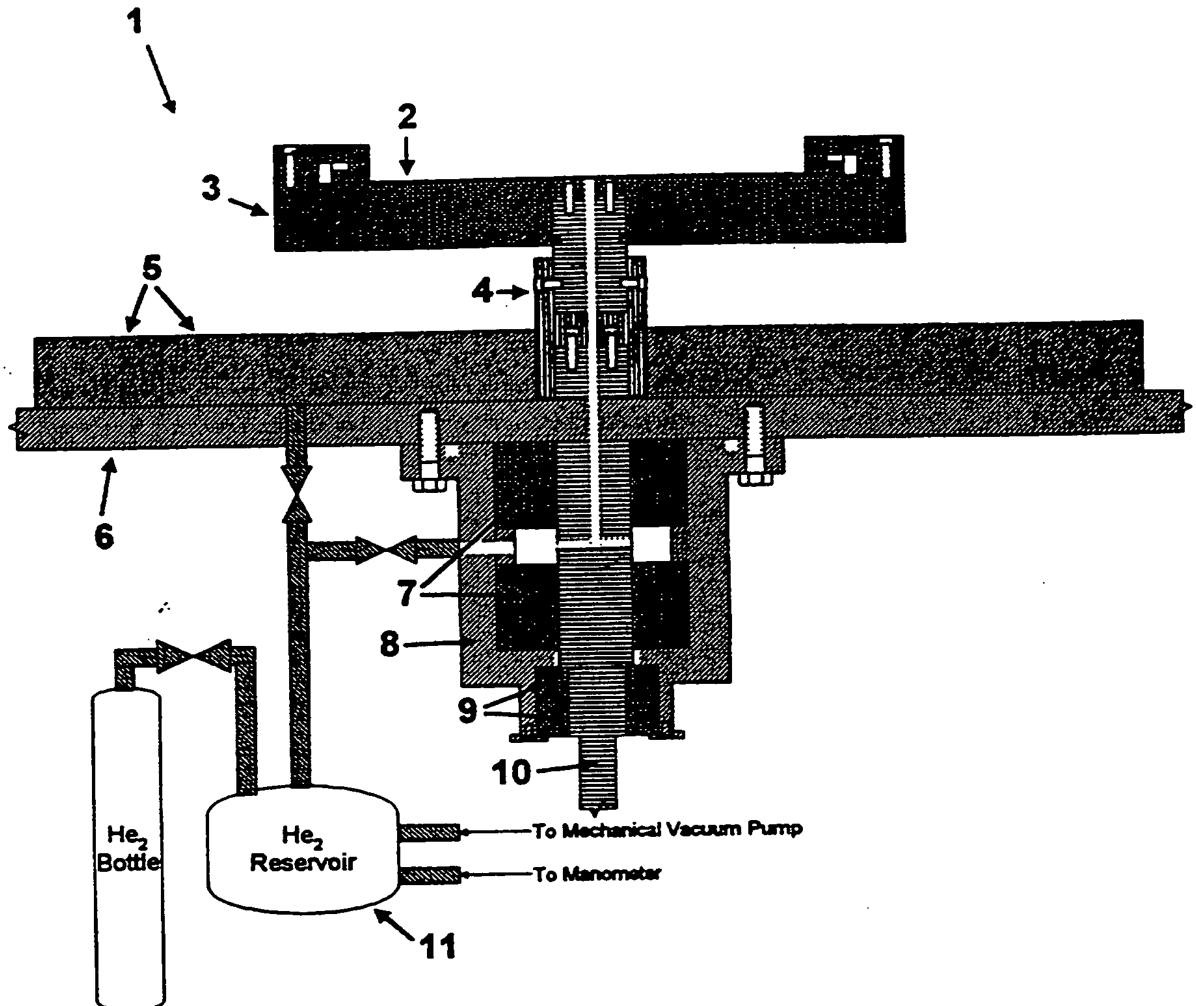

1
2
3
4
5
6
7
8
9
10
11
He$_2$ Bottle
He$_2$ Reservoir
To Mechanical Vacuum Pump
To Manometer

Fig. 1

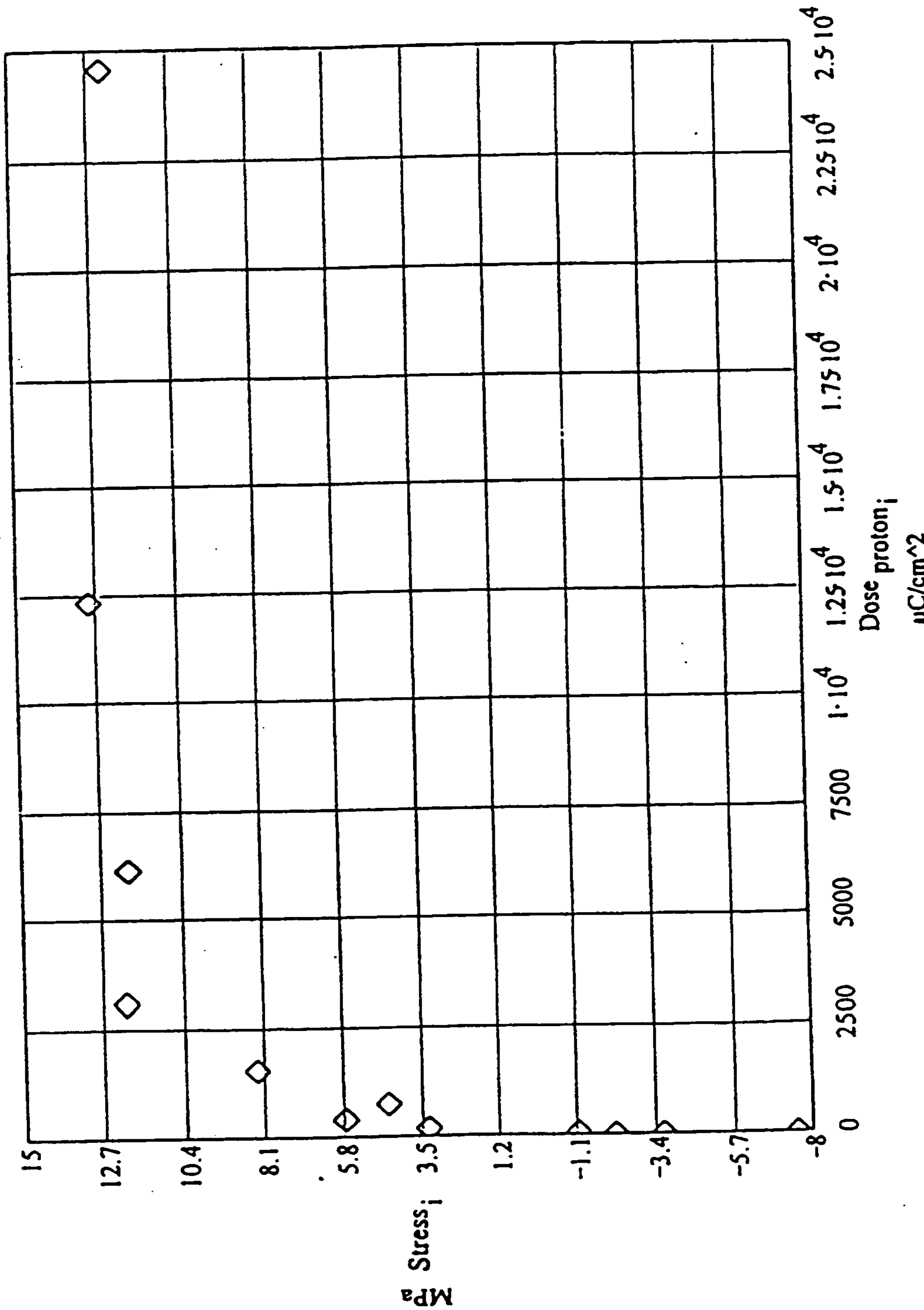

15
12.7
10.4
8.1
5.8
3.5
1.2
-1.1
-3.4
-5.7
-8
Stress$_i$
MPa
0
2500
5000
7500
$1 \cdot 10^4$
$1.25\,10^4$
$1.5\,10^4$
$1.75\,10^4$
$2 \cdot 10^4$
$2.25\,10^4$
$2.5\,10^4$
Dose$_{proton_i}$
μC/cm^2

FIG. 2

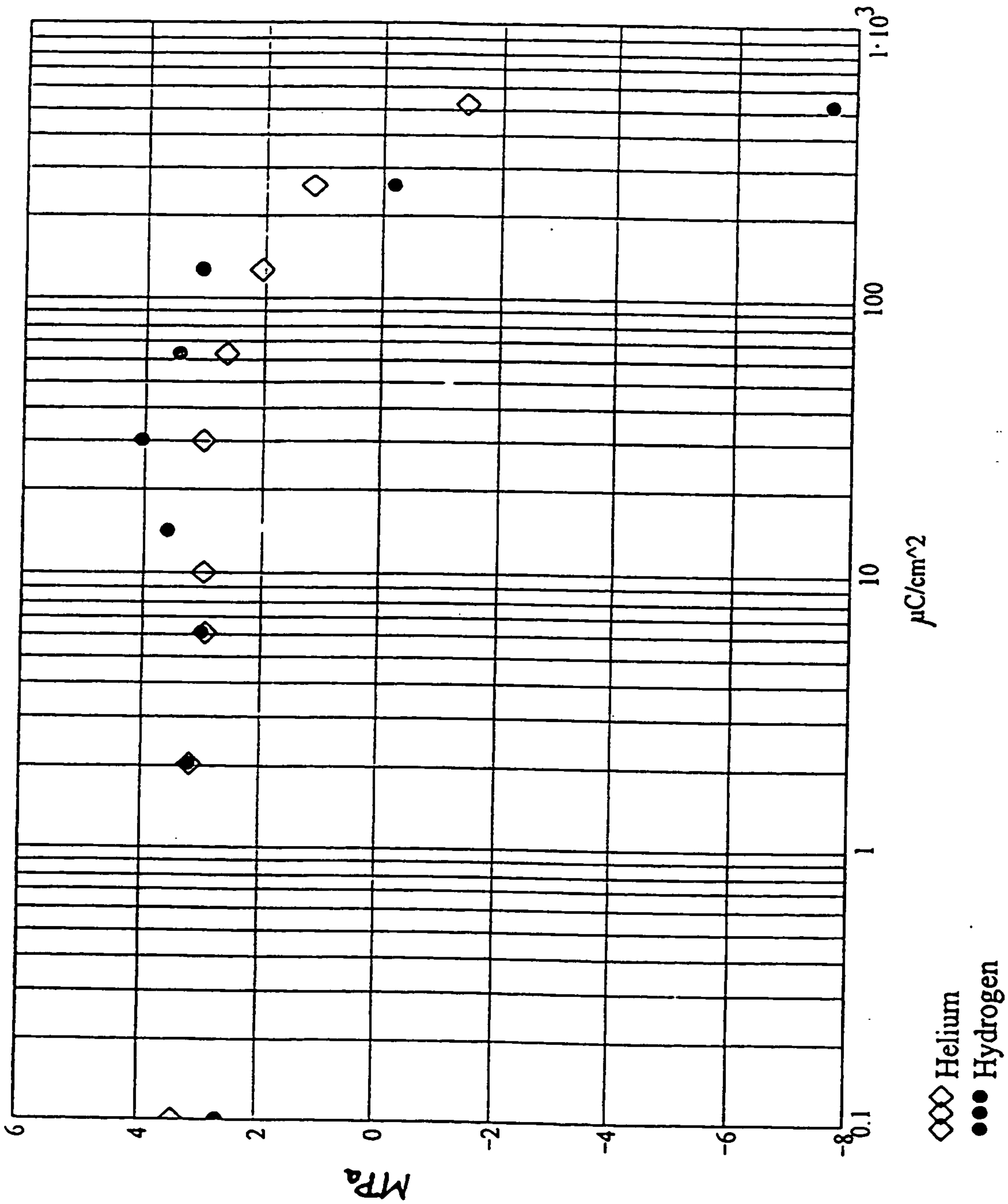


FIG. 3

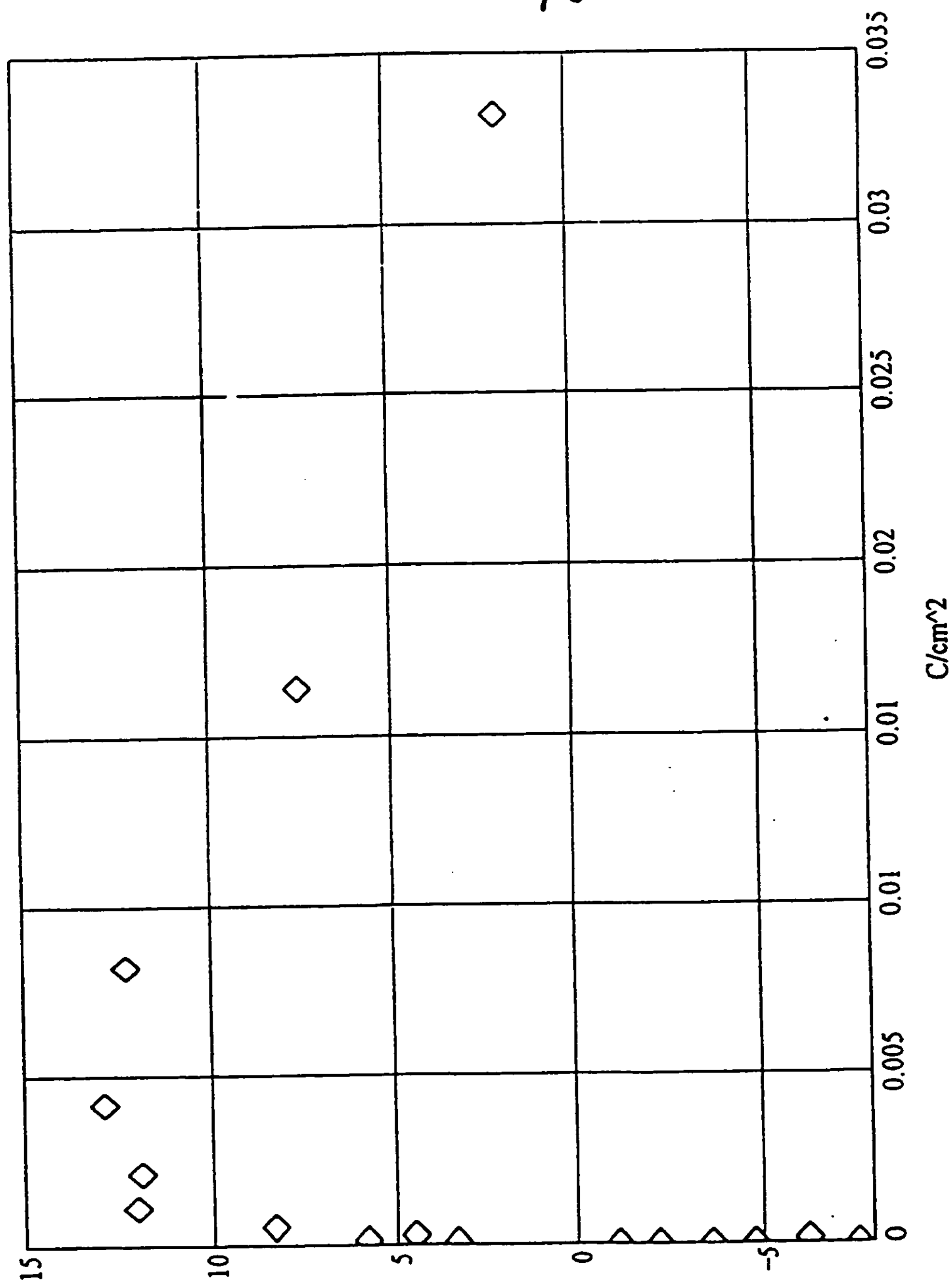


FIG. 4

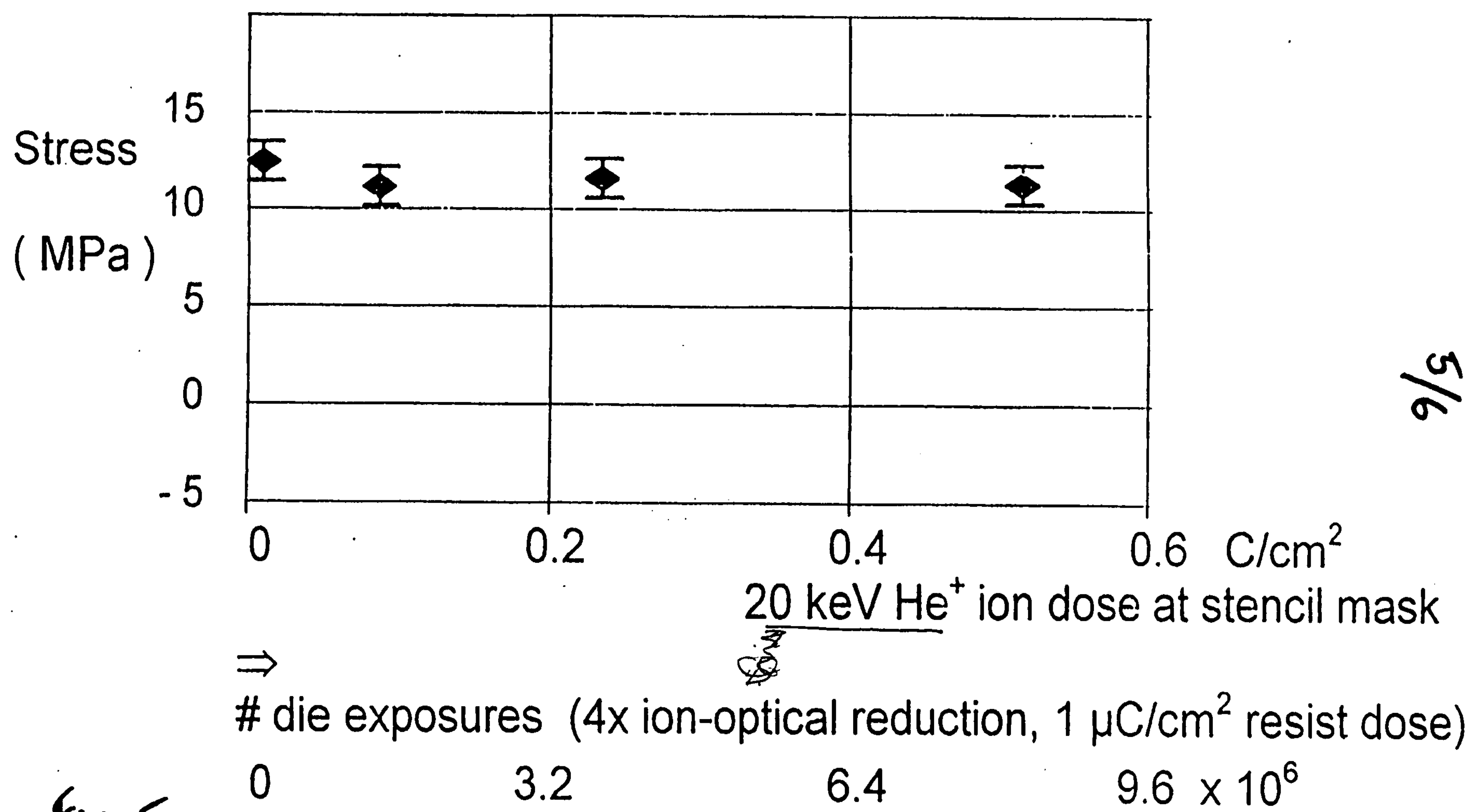
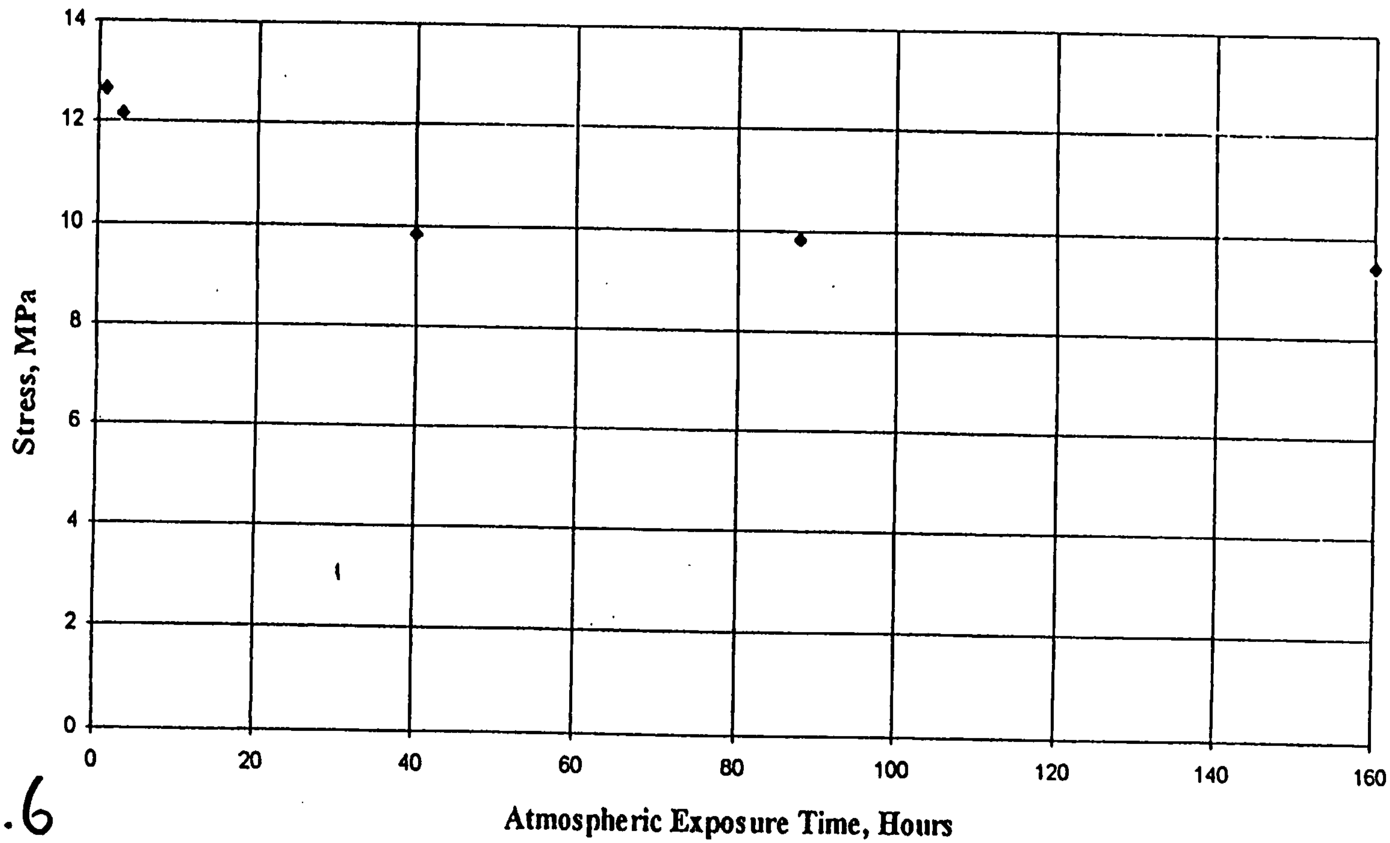

Stress
(MPa)
15
10
5
0
- 5
0
0.2
0.4
0.6 C/cm²
20 keV He⁺ ion dose at stencil mask
⇒
die exposures (4x ion-optical reduction, 1 μC/cm² resist dose)
0
3.2
6.4
9.6 x 10⁶

FIG.5



Stress, MPa
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
160
Atmospheric Exposure Time, Hours

FIG. 6

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METHOD FOR DEPOSITING A CARBON FILM ON A MEMBRANE

The present invention relates to membranes employed in X-ray and corpuscular projection lithography, e.g. as part of a stencil mask for ion-beam lithography.

In the manufacturing of e.g., semiconductors, X-ray and corpuscular beam lithography is used. Corpuscular beams include electrons, ions, but also neutral atoms and ionic or neutral molecules, e.g. hydrogen ions, H_3^+. In projection lithography membranes of various materials for masks to pattern the beam are used. The materials of these membranes can be of any material that can be formed as a thin layer and structured, including semiconductors, e.g. single-crystal α-silicon or polycrystalline silicon, metals, e.g. nickel, and insulators, e.g. silicon dioxide or aluminum oxide, many other materials can be, and are, used in the art. The life time of these membranes is limited by the effects of damage incurred to the membranes during irradiation. As for ion-beam lithography, a bare silicon membrane, which can be patterned and used as a stencil mask, can only withstand a total charge density of 0.2 mC/cm^2 of irradiated ions before its intrinsic stress changes drastically. To meet the needs of future lithography in VLSI and ULSI circuits, a mask will have to be capable of withstanding up to ten million exposures. This is approximately the number of exposures that can take place between design generations. The ion dose required to fully expose photoresist is approximately $5x10^{12}$ $ions/cm^2$. Therefore a stencil mask used in a proximity printer would be bombarded with $5x10^{19}$ $ions/cm^2$ or 8 C/cm^2 after ten million exposures. The ion beam could also be magnified or de-magnified as with an ion projection lithography system. With a demagnification of 4x, the stencil mask would be bombarded with $3.125x\ 10^{18}$ $ions/cm^2$, which equates with a total charge density of 500 mC/cm^2 at the stencil mask.

It has been shown previously that silicon membranes swell during lithium ion bombardment due to ion implantation into the silicon crystal interstitial positions. Hydrogen or helium

ions bombarding a silicon membrane also cause swelling which, in this case, is the main cause for stress change in the membrane. Hydrogen diffuses out of the silicon membrane when the temperature is set to 450°C for approximately 30 minutes, while helium diffuses out of the silicon membrane at a temperature of 700°C for approximately 8 hours. After the thermal treatment, the silicon membrane returns to its original tension for small doses, e.g. about 0.2 mC/cm²; for higher doses, the membrane is permanently damaged.

With masks of a material different from silicon, the problem stays in principle unchanged, although the extent of stress change due to irradiation can vary and even reverse, e.g. silicon dioxide shows a compaction rather than swelling upon irradiation with hydrogen, helium or argon ions. It is obvious that this phenomenon is not limited to the irradiation with ions but also with electrically neutral atoms or molecules. Moreover, since the lattice is affected by not only the implantation of atoms or molecules, but also the impact of the energetic radiation itself, stress change effects will prevail also for irradiation with electrons or high-energy electromagnetic radiation, as e.g. X-rays. The following discussion mainly refers to ion projection lithography, but it is understood that the considerations presented in the following also apply, with only minor adaptions, as e.g. taking the respective equivalent doses of irradiation, for the more general case of X-ray and corpuscular projection lithography.

In order to increase the life of a pattern mask used for ion-beam lithography, it is necessary to prevent the mask from swelling/compaction. This is usually done by means of protective coatings, as described in the Bohlen et al. U.S. Patent No. 4,448,865, an ideal ion-absorbing coating is characterized by the following properties:

a) the stress of the ion-absorbing coating should be in the order of or less than that of the silicon membrane;

b) the stress of the ion-absorbing coating should not change more than 10% when implanted with hydrogen or helium ion doses exceeding 1 C/cm²,

c) the stress of the ion-absorbing coating should not

change more than 10% when stored under typical clean-room conditions for periods up to 1 year;

d) the deposition and patterning of the ion-absorbing coating should be compatible with the mask fabrication sequence.

Especially the last requirement eliminates many potential candidates for the ion-absorbing layer. Carbon is a candidate film for this application since it can be easily patterned in oxygen; as additional advantages, it has only gaseous oxides and a high emissivity of between 0.7 and 0.8.

One technique to apply low-stress carbon films is sputtering. Another possible technique employs electron beam evaporation. The normal mode of sputtering is to place the substrate directly above the sputtering target. This so-called "on-axis" sputtering has been used extensively for the deposition of carbon films. However, carbon films produced by "on-axis" sputtering are diamond-like, have very high compressive stress, and should, when bombarded with ions, exhibit the problems discussed above, i.e., trapping of ions leading to swelling of the membrane, as well. Since implanted gasses cannot diffuse out of these films at room temperature, they are not suitable as ion-absorbing layers. The compressive stress of a diamond-like carbon film would also severely distort and/or destroy a membrane. The thin silicon membranes from which lithography masks are made have inherently about 10 MPa of tensile stress, whereas the intrinsic stress of diamond-like carbon is compressive and between 1 GPa and 14 GPa. In the conventional sputtering configuration, negative ions generated at the cathode bombard the substrate and create high-stress, diamond-like material. Carbon has been used as a conductive layer and to prevent sputtering, but carbon has not been applied for protecting e.g. silicon from ion implantation. Recently, however, a new sputter deposition technique, known as "off-axis" sputtering, has been developed for depositing high temperature superconducting films. This technique uses a different geometry in that the deposition surfaces are positioned in the off-axis configuration relative to the sputter targets. The technique of "off-axis" sputtering has been used in the deposition of superconducting films, as

described by Eom et al., Applied Physics Letters, vol. 55 (1989) p. 595.

It is an object of the present invention to provide a method to apply a carbon layer to membranes whose stress is small in comparison to the inner stress of the original membrane. It is another object of the present invention to provide a treatment to a carbon layer such that upon subsequent exposure, its stress does not change more than 10% with irradiation doses exceeding the equivalent of 500 mC/cm^2. The present invention further aims at a carbon layer to membranes, e.g. silicon membranes, used in ion-beam lithography in which the implanted gasses can diffuse out of the coating layer before swelling of the layer occurs.

A method is proposed for depositing carbon films on membranes used in masks for X-ray or corpuscular lithography, in which sputtering is used and the membranes serving as sputter substrates are positioned in the off-axis configuration relative to the sputter targets. In this configuration, the sputter gun faces away from the substrate and the sputtered particles diffuse onto the substrate. In this configuration, the sputtered particles will arrive at the substrate with energies low enough in order to produce films of the desired stress properties and low density.

In order to ensure good uniformity and maximum deposition rates, the operating pressure used in the above-described method is less than 30 mtorr. Furthermore, a temperature of the sputter targets above 550°C prevents the formation of insulating coatings on the target which may lead to arcing and reduce the sputtering rate; best results were obtained in the temperature range between 600°C and 1800°C.

For modifying the properties of carbon films after deposition, e.g. the deactivation of chemically reactive sites or stabilizing of stress, ion bombardment with helium ions can be employed. This method anticipates changes in the film due to initial irradiation and serves to reach a plateau in which the stress varies only little, i.e. within an interval of about 1 MPa or less. The ion energies are chosen conveniently such that the projected range of the helium ions corresponds to the thickness of the carbon coating, but is still less, in order to avoid implantation to the membrane beneath the carbon film. In practice it was found that the minimum dose for the conversion is about 120 mC/cm².

It is an important property of the invention presented that the carbon coating films thus produced have a compressive stress of the order of 10 MPa or below, which is low in comparison with that of the diamond-like films produced by methods well-known, and that this stress can be stabilized in the sense of the already mentioned plateau.

One important field of use for these carbon-coated membranes is ion projection lithography. For protection of the membrane, it is advantageous when the membrane has at least

such a thickness, that ion penetration into the membrane is prevented at the ion energies intended.

If radiation cooling of the membrane is important, the emissivity of the coating film has to be large. Although the emissivity of a film coating according to this invention will not be the same as the bulk emissivity of carbon, which is 0.7 to 0.8, it was found that emissivity values above 0.5 can easily be obtained, and an emissivity of 0.75 is reached for a film approximately one micron thick.

The invention is described further hereinafter, by way of example only, with reference to the accompanying drawings in which:

FIG. 1 is a schematic overview of an "off-axis" sputtering assembly for carbon films according to the present invention.

FIG. 2 shows the dependence of membrane stress as function of the ion dose of a silicon membrane coated with 0.5 μm carbon film and bombarded with hydrogen ions at an energy of 10 keV per ion.

FIG. 3 shows the dependence of membrane stress as function of the ion dose of two bare silicon membranes, one bombarded with hydrogen ions at an energy of 10 keV per ion, the other bombarded with helium ions at an energy of 30 keV per ion.

FIG. 4 shows the dependence of membrane stress as a function of the ion dose of a silicon membrane coated with 0.5 μm carbon film and bombarded with hydrogen ions at an energy of 10 keV per ion.

FIG. 5 shows the dependence of the stress of a 2.5 μm thick silicon membrane with a 1.0μm thick protective carbon coating membrane upon irradiation with helium ions at an energy of 20 keV per ion. The membrane was initially irradiated with helium ions at an energy of 80 kev to a dose of 5 mC/cm^2 and then at an energy of 30 kev to an additional dose of 0.6 C/cm^2.

FIG. 6 shows behavior of the membrane stress during atmospheric exposure of a membrane after irradiation with helium ions at an energy of 20 kev to a dose of 0.25C/cm^2.

In the "off-axis" configuration, the substrate is mounted in such a way within the sputtering chamber that the at least one sputter gun, also mounted in the sputtering chamber and comprising each an anode and a sputter target working as a cathode, faces away from the substrate surface where the film is to be deposited. An example of a sputtering assembly is shown in FIG. 1 and discussed in the Examples section. The main deposition mechanism is diffusion of the sputter material in the gas within the sputtering chamber held at low pressure as described below. The sputtered particles are scattered by gas molecules and reach the substrate after having undergone several scattering collisions, the average number of collisions determined by the geometry and gas pressure of the sputter assembly. This deposition mechanism makes sure that the sputtered particles have low energies of deposition on the substrate. High-energy negative ions generated at the cathode, e.g. negative carbon ions, are prevented from bombarding the substrate. In the invention presented, the sputter target material is graphite. The graphite targets need to be heatable and heat-controlled so as to meet the process conditions described below. On the other hand, it is recommended that the temperature of the substrate, which may be a delicate pattern structuring, be kept at ambient temperature.

To apply a porous ion-absorbing film with low stress, the gas pressure within the sputter chamber needs to be between 1 mtorr and 30 mtorr. Using the "off-axis" configuration requires a low operating pressure so that sputtered atoms have a sufficiently long mean free path to be scattered onto the substrate. At 30 mtorr, a sputtered atom will typically have made several tens of scattering collisions and would be re-deposited on or near the target. At pressures exceeding 30 mtorr, the mean free path of a sputtered atom is further reduced and deposition is severely obstructed.

It was discovered that DC sputtering of a cold graphite target generated severe arcing. This is probably due to the formation of an insulating carbon layer on the target due to argon ion bombardment. This layer forms an insulator which becomes electrically charged by the electrons travelling in the

race track of the target. When this charging effect has produced a voltage higher than the breakdown voltage of the insulating coating, an arc will travel through the coating. These arcs generate particulate defects in the carbon film and prevent a stable deposition. Arcing may also extinguish the plasma by consuming the secondary electrons needed to sustain the plasma and, even worse, the arc can eject macroscopic particles from the target, which will severely degrade the performance of the carbon film. We have found that arcing is completely absent if the target is operated at temperatures above 500°C, whereas the substrate is kept at ambient temperature throughout. We believe that a high target temperature converts the insulating coating to graphite. Sputtering on hot targets is described in the Chau et al. U.S. Patent No. 5,415,756. Coatings have been formed with target temperatures between 600°C and 2400°C. High temperatures were previously used to evaporate insulating target coatings in DC relative sputtering, but evaporation is clearly not the mechanism of removal of (insulating) coatings in this case.

Whilst the visual appearance of carbon films deposited by "on-axis" sputtering are shiny and/or glassy, and black or gray in color, the carbon films deposited by the "off-axis" sputtering are dull and black in color. The hardness of an "on-axis" film is much greater than the hardness of an "off-axis" film. The increased hardness of an "on-axis" film can be attributed to atomic peening of the substrate by negative carbon ions and reflected sputter gas neutrals. The densities of "off-axis" films were found to be in the range of 1.5 g/cm^3 which is distinctly lower than that of bulk graphite, namely 2.2 g/cm^3.

The thickness of the carbon film to be deposited can be up to several μm, and will be chosen according to the intended energy of irradiation. For ion-beam exposure, the thickness of the film should be such that the ions are absorbed within the carbon coating and do not reach the membrane underneath. For instance, a layer of about 0.5 μm is assumed to be sufficient in this aspect for hydrogen or helium ions of 10 keV.

When a silicon membrane is covered with a protective carbon film, the total stress in the membrane is lowered

depending on the film thickness. However, when the membrane is exposed to hydrogen (or helium) ions, the stress in the membrane increases to a plateau. FIG. 2 shows the dependence of the membrane stress as a function of the hydrogen ion dose for a silicon membrane coated with 0.5 μm carbon film. The membrane was bombarded with hydrogen ions at an energy of 10 keV per ion. The plateau reached is approximately 12 MPa of tensile stress. It was found that the stress in the membrane maintained this plateau value until the proton dose delivered to the membrane was approximately 25 mC/cm^2, i.e., 1.536×10^{17} protons. With this charge density, the membrane could be used to perform approximately 500,000 exposures in a 4x lithography system, given that 5×10^{12} $ions/cm^2$ are needed to fully expose photoresist. All stress values of the figures are given in MPa.

It was observed that carbon etching occurs upon hydrogen bombardment, but the detailed mechanism is not yet clear. As a possible hypothesis, after the hydrogen implanted has lost enough energy, hydrogen and carbon form a hydrocarbon such as methane, CH_4, which out-gasses from the surface and is pumped off, this process leading to an increase of the film porosity and thus influencing the behavior shown in FIG. 2.

An example for a sputter assembly for deposition of carbon films on e.g. silicon masks according to the present invention is depicted schematically in FIG. 1. The assembly 1 uses five Research S-guns 5 (Sputtered Films, Inc.), each containing an anode and a graphite sputter target and capable of 2.4 kilowatts of dc power dissipation. The S-guns 5 are evenly positioned in a ten-inch diameter circle on a base plate 6 with the substrate 2 placed on a substrate holder 3 at the center. The substrate 2 is electrically floating and can be cooled with helium gas from a helium reservoir 11 through the substrate holder 3. The substrate holder 3 rotates during deposition, and is driven via a shaft 10 to which it is connected through a TEFLON® (polytetrafluoroethylene) coupler 4 mounted to the base plate 6 using a spacer sleeve 8 and thrust bearings 9 and vacuum-sealed by means of FERROFLUIDIC™ seals 7. The assembly is housed in a 58 cm diameter by 47 cm tall stainless-steel

chamber (not shown in FIG. 1) which the base plate 6 is a part of, and is pumped by a cryogenic pump (CTI-10, Cryogenic Inc.). The deposition rate typically is in the range between 1 and 2.5 microns/hour, depending upon operating pressure and sputter power.

For comparison, an example of bare silicon membranes is displayed in FIG. 3 showing the dependence of mask stress on ion dose for bare silicon membranes bombarded by 10 keV hydrogen, represented by circles, and 30 keV helium ions, represented by diamonds. A charge dose of only 0.2 mC/cm² is needed to completely remove the initial tension of the membrane.

The stress values given here have been determined by contact-free measuring the distortion of the membrane using a laser upon creating a bulging of the membrane by applying different pressures at either side of the membrane. The stress in the carbon layer was determined from measurement of the total stress and comparison with that of the bare membrane.

FIG. 4 shows the dependence of membrane stress on charge dose for a 2.5 μm thick silicon membrane with a 0.5 μm thick protective carbon coating bombarded by 10 keV hydrogen ions. The initial stress of the carbon film is about -90 MPa (negative values denote compressive stress). This compression is probably not an intrinsic property of the deposited film, but is caused by the absorption of water vapor by active sites in the film. The film is a form of "activated carbon." However, when the membrane is exposed to hydrogen ions with an energy of 10 keV per proton, the stress of the composite membrane increases to a plateau of about 12 MPa indicating that the film tension is about 32 MPa. This could be due to desorption of water vapor, but other processes may be involved. The membrane maintained this stress value until the charge dose delivered to the membrane/film was approximately 25 mC/cm². With this charge density, the membrane could be used to make approximately 500,000 exposures in a 4x lithography system, assuming a resist sensitivity of $5x10^{12}$ ions/cm².

For doses greater than 10 mC/cm², the stress becomes increasingly compressive because ions are penetrating through the carbon layer into the silicon. The carbon layer is visibly

thinner than the initial coating. We believe that reactive etching of the carbon by hydrogen forming volatile hydrocarbons such a methane, CH_4 is responsible for the thinning of the carbon layer. The use of hydrogen as an ion source is not ideal due to the volume etching of the applied film. Studies were therefore begun with helium, which clearly will not have this problem. Therefore, the next experiment involved implanting the carbon film using helium ions at 20 keV.

FIG. 5 shows the behavior of the membrane stress during helium bombardment of a 2.5μm thick silicon membrane with a 1.0 μm thick protective carbon coating membrane. The film was initially bombarded using helium ions by 80 keV ions with a dose of 0.005 C/cm². The energy was chosen so that the ions would convert nearly the entire carbon layer without penetrating into the silicon. The voltage was then reduced to 30 keV and 0.6 C/cm² were applied. The voltage was now decreased to 20 keV, and FIG. 5 shows the stress data taken during the irradiation with these 20 kev helium ions up to 0.835 C/cm². The stress was then stable, within experimental error, up to a total dose of 1.44 C/cm². The corresponding number of die exposures is also indicated in FIG. 5, an ion dose of 0.1 C/cm² equating with 1.6 million die exposures in a 4x projection lithography system, assuming a 1 μC/cm² resist dose.

After this procedure, the behavior of the membrane stress under atmospheric conditions was taken. FIG. 6 shows the stress in the carbon film of the membrane drawn over the time of atmospheric exposure. The stress varies by less than 3 Mpa over a period of 160 hours. This small variation is believed to be due to a region of unbombarded carbon surrounding the converted region. This demonstrates that the initial activated carbon film had been converted to one which is environmentally stable for at least one week.

It will be recognized that the present invention is not to be limited to the specific form(s) described above; rather, it is understood that other embodiments can be found without departing from the spirit and scope of the invention defined in the following claims.

CLAIMS

1. A method of depositing carbon film on a membrane for use in X-ray or corpuscular projection lithography as at least part of a lithography component and comprising sputtering, wherein the membrane is arranged to serve as a sputter substrate, and the method includes positioning the membrane in an off-axis configuration relative to the at least one sputter target.

2. The method as claimed in Claim 1, wherein at least one sputter target is employed with a temperature greater than 550°C.

3. The method as claimed in Claim 2, wherein the temperature of all sputter targets is between 600°C and 1800°C.

4. The method as claimed in Claim 1, wherein the operating pressure during sputtering is less than 30 mtorr.

5. A method of modifying carbon films produced according to the method of Claim 1, 2, 3 or 4, wherein said films are implanted with helium ions by ion bombardment at ion energies such that said helium ions have a projected range of implantation no greater than the thickness of said films.

6. The method as claimed in Claim 5, wherein the minimum dose for the conversion desired is 12 mC/cm^2.

7. The method as claimed in Claim 5 or 6, wherein the carbon film has a low compressive stress of 10 MPa or below.

8. The method as claimed in Claim 5, 6 or 7, in which the projection lithography comprises projection lithography and the membrane is used as part of a stencil mask.

9. The method as claimed in Claim 5, 6, 7 or 8, wherein the material of the membrane is silicon.

10. A corpuscular projection lithography membrane having, at the surface exposed to an ion beam, a film having at least such a thickness preventing ion penetration into the membrane, the film comprising a carbon layer deposited by off-axis sputtering.

11. The membrane as claimed in Claim 10, wherein the membrane material comprises silicon.

12. The membrane as claimed in Claim 10 or 11, wherein the emissivity of the carbon layer is above 0.5.

13. The membrane as claimed in Claim 12, wherein the emissivity of the carbon layer is in the range of 0.7 to 0.8.

14. A method of depositing carbon film on a membrane for use in X-ray or corpuscular projection lithography substantially as hereinbefore described with reference to, and as illustrated in the accompanying drawings.

15. A method of modifying carbon films produced in accordance with the method of claim 14 and substantially as hereinafter described with reference to, and as illustrated in, the accompanying drawings.

16. A corpuscular projection lithography membrane substantially as hereinafter described with reference to, and as illustrated in, the accompanying drawings.

The Patent Office

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Application No: GB 9810993.7
Claims searched: 1-16

Examiner: Matthew Lawson
Date of search: 5 August 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): C7F (FCAS, FCSE, FCSL, FCSM, FCSX)

Int Cl (Ed.6): C23C 14/06, 14/34, 14/36, 14/38, 14/40, 14/42, 14/44; G03F 1/16

Other: Online: INSPEC, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Rel vant to claims
Y	EP 0231894 A1	(K.K. MEIDENSHA) page 7 lines 11-27 and the relative position of the graphite target 44 & the substrate 64 in figure 1.	1,10-13
Y	US 4448865	(BOHLEN) column 7 lines 1-26, column 10 lines 15-28 and figures 1C & 2H.	1,10-13
A	EP 0470379 A1	(SHIN-ETSU) column 1 lines 3-13, column 2 lines 20-28.	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.